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Photoablation of Bone by Excimer Laser Radiation

Markus L. Walter, MD,[1]* Michael E. Domes, MD,[2] Ricarda A. Diller, MD,[3]
Julia Sproedt, MD,[1] and Uwe H. Joosten, MD[1]

[1]Department of Trauma and Hand Surgery, Medical Center of the Westfalian Wilhelms University, 48129 Münster, Germany
[2]Department of Orthopaedics, Medical Center of the Westfalian Wilhelms University, 48129 Münster, Germany
[3]Department of General Surgery, Medical Center of the Westfalian Wilhelms University, 48129 Münster, Germany

Background and Objectives: **The aim of the present study was to compare the usefulness of mechanical osteotomy tools and common laser systems with the ultraviolet (UV) laser in the field of the central nervous system and its bony capsule.**
Study Design/Materials and Methods: **The cranial bones of 42 living rats were treated with UV laser radiation with wavelengths of 193 nm and 248 nm. The morphology and physical effects were evaluated by means of optical and scanning electron microscopy.**
Results: **This study shows the special characteristics of excimer versus infrared lasers or mechanical tools, such as high precision, no thermic damage, little depth effect, and no delay of healing processes.**
Conclusion: **The excimer laser is an interesting instrument for microsurgery of bones in orthopaedics, neurosurgery, and otolaryngology. Lasers Surg. Med. 25:153–158, 1999.**

Key words: **microsurgery of the bone; neurosurgery; orthopedics; ultraviolet laser radiation**

INTRODUCTION

There have been only a few trials on bone surgery using high thermic lasers. The results were poor because of the environmental thermic injury leading to delayed bone healing [1,2]. Recent studies on ultraviolet (UV) lasers have dealt with its effects on cartilage or cornea [3–7]. To our knowledge, only few data are available on investigations dealing with the effects of UV lasers on bones [8], especially the effect of photoablation, a type of "cold" laser light [9] that typifies the UV laser, and its applicability to bony structures.

The benefits of excimer lasers are high precision, low depth impact, and lack of heat development. Low output density, lack of coagulation effect, and technical limits constrict their use to microsurgery of bradytrophic tissue only. We believe that the bony structures of the cerebrospinal system are appropriate for using the touchless laser energy because the use of mechanical tools poses high risks. The aim of the present study was to investigate the biological effects UV laser has on bones.

MATERIALS AND METHODS

Lasers

Two excimer lasers were used (Lambda Physics). One laser had a wavelength of 248 nm and a maximum output of 500 mJ/cm^2. The other had a wavelength of 193 nm and a maximum out-

*Correspondence to: Markus L. Walter, MD, Department of Trauma and Hand Surgery, Medical Center of the Westfalian Wilhelms University, Waldeyerstr. 1, 48129 Münster, Germany.

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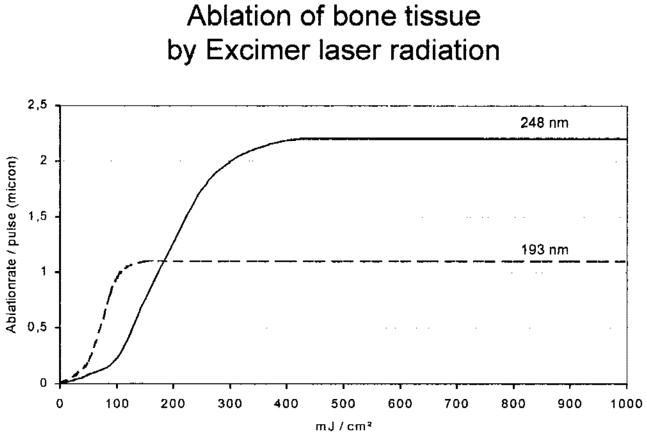

Fig. 1. Satiation effect in spite of raising energy

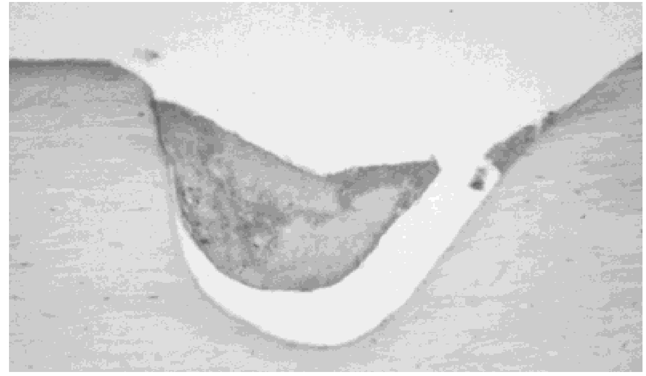

Fig. 2. Bone defect created by an excimer laser with a wavelength of 193 nm. Hematoxylin and eosin stain, magnification 40×.

put of 250 mJ/cm^2. We used a small pilot laser to focus and adjust the target field.

Resonators

Ultraviolet lasers characteristically create a high spread of radiation when used at stable resonators. Therefore, we decided to use unstable resonators to achieve a better focus.

Material Set-up

The distinguishing features of the excimer laser, nonlinear and nonthermic photoablation, were applied on laboratory animals placed on a multimobile operation table. The size of the irradiation fields was 1 mm^2. To observe the laser, we installed a stereo theater microscope with 30-fold magnification.

Bone Tissue

Forty-two male Wistar rats (age range = 6–9 months), with an average weight of 450 g, were used. After administering ether anesthesia, the rats were given an intraperitoneal injection of ketamine and pentobarbital, with the dose depending on their body weights. Under sterile conditions, the skull of each rat was exposed and the irradiation fields were defined. To prevent damage to the superior sagittal sinus (in case the laser penetrated the skull), the irradiation fields were strictly arranged in paramedian positions. The irradiation was halted if there was a "wear out" effect or if trepanation was visible. One irradiation series was performed at a wavelength of 248 nm (n = 32) and the other at a wavelength of 193 nm (n = 10). From both groups, animals were selected for survival (n = 6 and 4, respectively). For each laser impulse, the following criteria were evaluated: wavelength (nm), size of irradiated field (mm^2), energy of each laser impulse (mJ), irradiation power (mJ/cm^2), frequency, and number of laser impulses per lesion (n).

TABLE 1. Ablationrate Due to Laser Energy in μm/Pulse

Frequency	193 nm	248 nm
Liminal energy density	100 mJ/cm^2	140 mJ/cm^2
Optimal ablation	250 mJ/cm^2	500 mJ/cm^2
Ablation rate	1 micron/shot	2 micron/shot

Histology/Pathology

The generated bone defects were controlled with an optical microscope (OM) and a scanning electron microscope (SEM). Ten slices stained with hematoxylin and eosin were evaluated and photographed under 40–50-fold magnification. For the three-dimensional impression, several specimens were controlled with the SEM. The healing processes of 10 rats were examined after

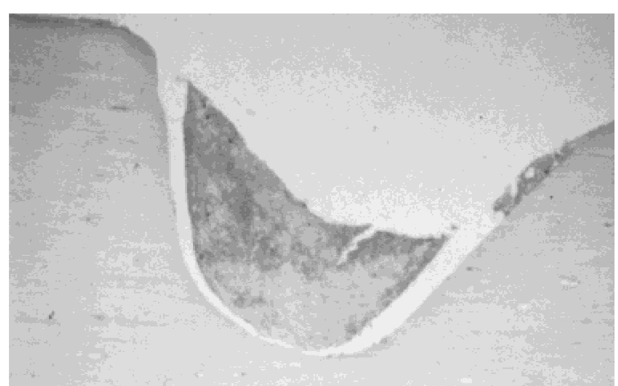

Fig. 3. Bone defect created by an excimer laser with a wavelength of 193 nm. Hematoxylin and eosin stain, magnification 40×.

Fig. 4. Bone defect created by an excimer laser with a wavelength of 193 nm. Hematoxylin and eosin stain, magnification 50×.

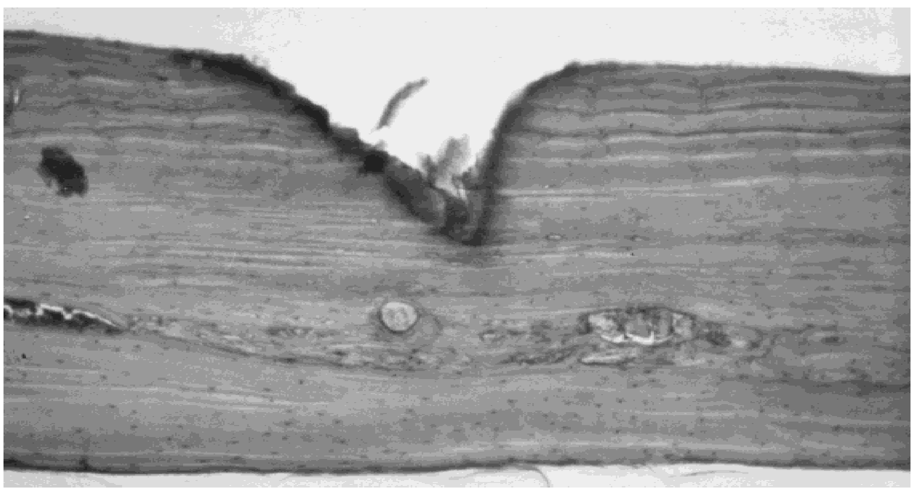

Fig. 5. Bone defect created by an excimer laser with a wavelength of 248 nm. Hematoxylin and eosin stain, magnification 40×.

10, 30, and 100 days. The histopathologic reconditioning was focused particularly on perifocal tissue damage and postulated bone-healing dysfunction.

RESULTS

We first measured the threshold energy, which produced a visible lesion of the irradiated tissue and indicates the beginning of the photoablation of the bone. For both lasers, the values could be evaluated (Table 1). The ablation rates were 1 μ at 193-nm wavelength per pulse and 2 μ at 248-nm wavelength per pulse (Table 1), obtained by an energy of 250 mJ/cm^2 at 193 nm and 500 mJ/cm^2 at 248 nm. An increase of the ablation rate could not be observed at a higher irradiation power, which implies an effect of saturation (Fig. 1). These parameters are shown in Figure 1 and Table 1.

The excimer laser produced a very low depth effect. After irradiation at a wavelength of 193 nm, the zone of necrosis was 0.05 mm in diameter; at a wavelength of 248 nm, the zone increased to a maximum of 0.1 mm in diameter. In all cases, we saw no perifocal damage or tissue tears, vessel lesions, or cellular decay. Even slight blood accumulation, present in the irradiation funnel, caused a reduction or, at times, a total loss of the laser effect. The figures show some of the OM and SEM findings.

Figures 2 and 3 show the highly precise tissue ablation with the low-frequency irradiation (193 nm). The zone of necrosis is almost invisible, and there are no depth effects. A long-distance effect of vaporization during the run-up could not

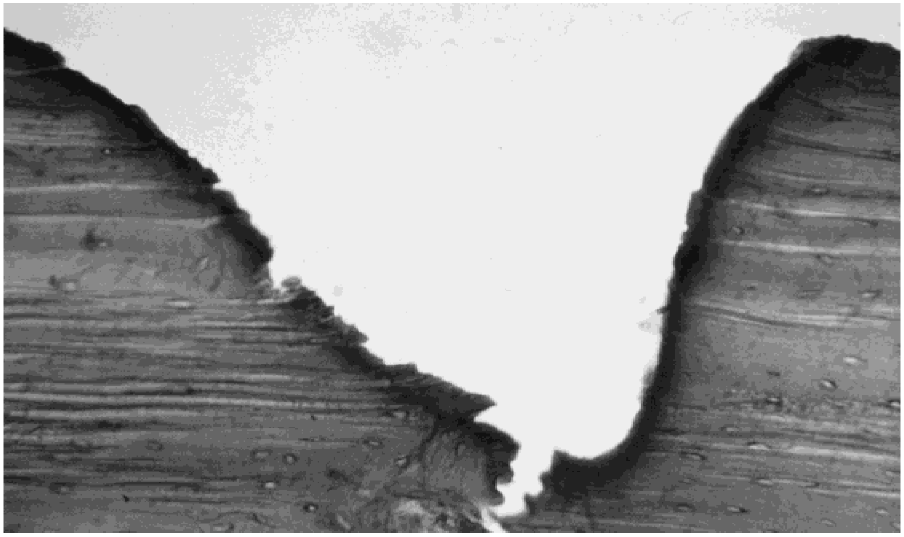

Fig. 6. Bone defect created by an excimer laser with a wavelength of 248 nm. Hematoxylin and eosin stain, magnification 64×.

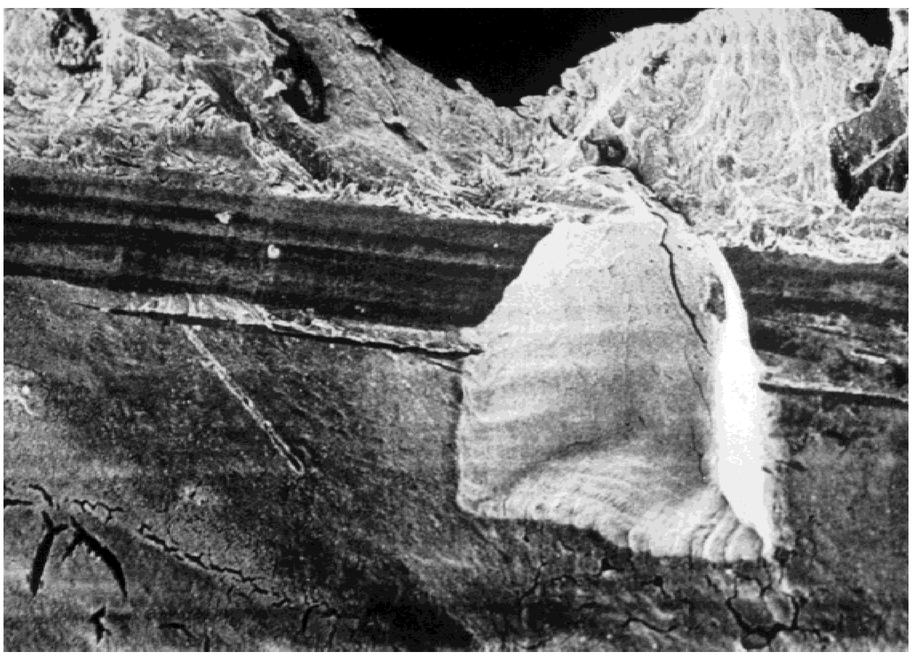

Fig. 7. Scanning electron microscopy. Bone defect created by an eximer laser with a wavelength of 193 nm. Magnification 52×.

be identified. The continuity of perifocal blood vessels was maintained (Fig. 4). The immediate loss of effect was obvious when there was bleeding or fluid accumulation in the irradiation field. There was no coagulation effect in cases of accidental bleeding of intrabony vessels.

The results with the 193-nm laser are, to a lesser extent, transferable to the 248-nm laser. The zone of necrosis is more clearly visible and the vaporization is not as accurately developed. No depth or coagulation effects are visible (Figs. 5, 6). The differences in energy per laser impulse, in irradiation power per square centimeter, and the variable pulse frequency did not cause significant changes in the study findings.

The SEM reconditioning shows the impressive possibility of the precise microsurgical treatment of bone tissue (Fig. 7). Bone healing processes could be demonstrated in the surviving rats. There was evidence of a totally uninfluenced primary ossification of the lesions 10, 30, and 100 days within normal time. The danger of creating a pseudoarthrosis was not apparent. The animals examined, after 10 days of convalescence, showed a replenishment of the lesions with organized hematomas interspersed with granulocytes and fibroblasts. Twenty days later, the microscopic examination showed advanced restitution with immigrated osteoblasts and focal bony neoformations (Fig. 8). The restitution ad integrum was

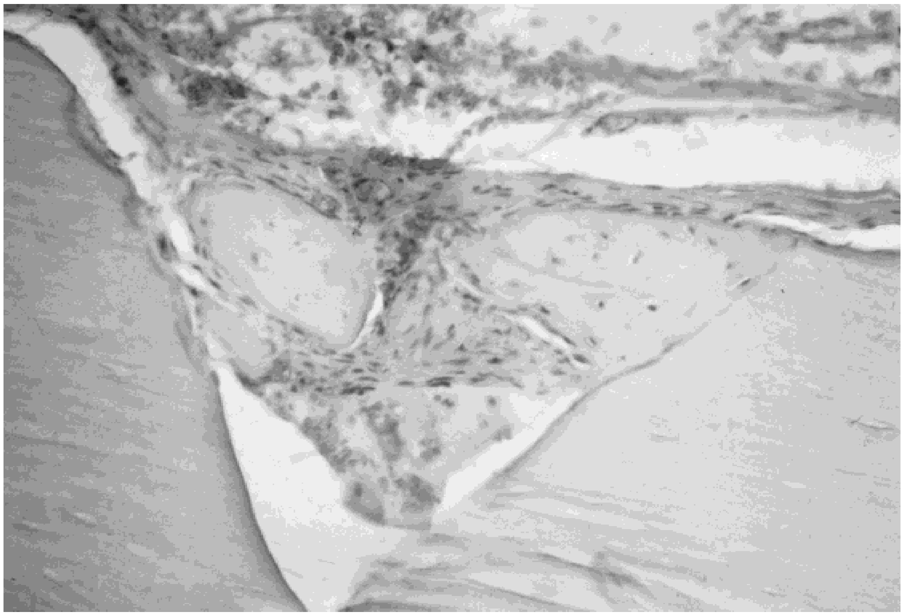

Fig. 8. Bone defect created by an excimer laser with a wavelength of 193 nm after 30 days of survival. Hematoxylin and eosin stain, magnification 50×.

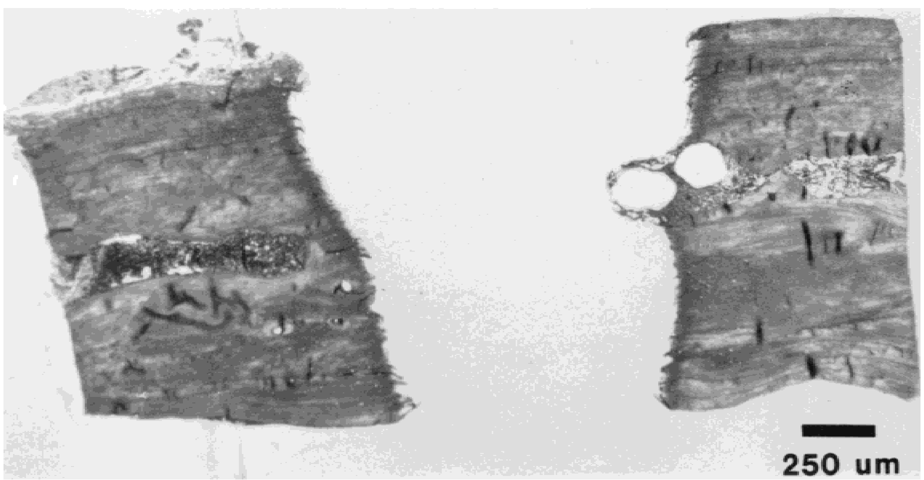

Fig. 9. Bone defect created by a continuous wave Nd:YAG laser (wavelength = 1.064 μm) [2].

achieved 100 days after treatment. The lesions from the laser seemed to be completely healed because they could no longer be identified microscopically.

DISCUSSION

The bone defects created by the excimer laser are equivalent to bone defects caused by high-precision mechanical tools. The bone healing, shown with regard to both wavelengths, indicates the advantages of this technique over thermic lasers.

The OM and SEM findings in 42 rats permit a positive assessment of UV lasers as tools in the microsurgery of bones in the future. Specific clinical applications [10–12] have confirmed this optimism. The excimer laser, because of its precise tissue ablation and depending on its power density and wavelength, can be used as an additional tool of microsurgical instrumentation. It offers vibration-free handling and, as a consequence, safe application and negligible depth effects. A disadvantage of this type of laser is the missing hemostatic component, which limits its use, to a great extent, to bradytrophic tissue. In comparison with CO_2, Nd:YAG, and other thermic lasers, whose use on bones has been researched by Nuss et al. in 1988 [2], the excimer laser shows significant advantages.

Figures 9 and 10 from Nuss et al. [2] show bone tissue with lesions created by continuous

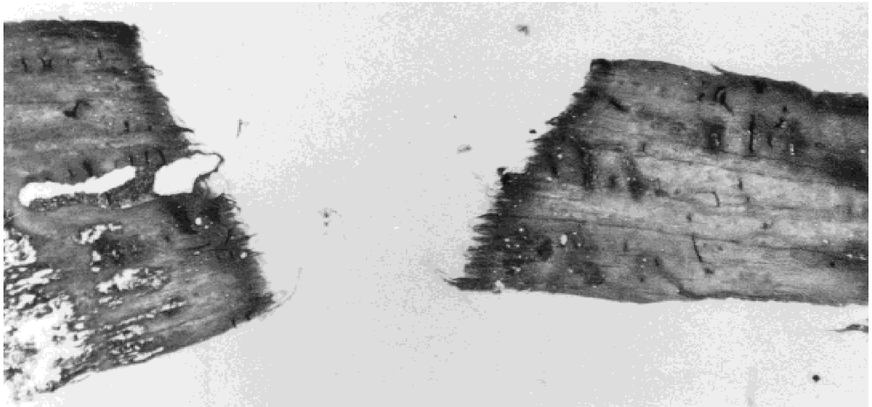

Fig. 10. Bone defect created by a continuous wave CO_2 laser (wavelength = 10.6 μm) [2].

wave Nd:YAG (wavelength = 1.064 μm; Fig. 9) and CO_2 (wavelength 10.6 μm; Fig. 10) lasers. These lasers differ in wavelength (IR) and irradiation mode (CW/pulse) from the laser used in the present study. There is no doubt that the irradiated material in that study shows significant differences from the bone tissue used in the present trial. In that study [2], surface was damaged and the irradiation line was clearly deeper, which led to pseudoarthrosis [1]. These disadvantages show that the excimer laser may be a superior tool in the microsurgery of bones.

In our opinion, the excimer laser has its legitimacy in orthopedics, neurosurgery of spinal and intracranial nerve decompression, and cartilage surgery during arthroscopic operations [13,14]. In addition, this laser is a very useful tool for interventions in otolaryngology, in particular for surgery of the middle ear and maxillofacial surgery. However, using different lasers is expensive, which restricts its application to large centers. Furthermore, the industry will have to provide clinically suitable systems.

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